Detection of soft gamma-ray emission from the Seyfert II galaxy NGC 4507 by the OSSE telescope

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ABSTRACT

We report the first soft gamma-ray observation by the OSSE experiment onboard the CGRO of the optically selected Seyfert II galaxy, NGC 4507. The source was observed on two separate weeks in 1993 and detected between 50 and 200 keV at a confidence level of 7σ. There is no evidence of flux variability within or between the two observation periods which sample timescales from days to months. The source spectrum obtained from combining the two sets of data is best described by spectral forms including some exponential cutoff. For example the best fit thermal bremsstrahlung model provides a temperature of kT=95^{+31}_{-25} while a thermal Comptonization model gives a plasma temperature of 44^{+7}_{-9} keV for an optical depth of 3; the 100 keV intensity is typically 5 10^{-6} photons cm^{-2} s^{-1} keV^{-1}. The observed shape is steeper than the one observed by GINGA in the X-ray band in 1990. The joint GINGA/OSSE spectrum is best described by an absorbed power law exponentially cutoff at high energies and having an iron K α emission line;acceptable fits can be obtained without (f_r=0) or with (f_r=1) a Compton reflection component. In the first case we find a harder photon index (, =1.3 $\pm$ 0.2)) and a lower cutoff energy (E_c=73^{+48}_{-24} keV) than in Seyfert I galaxies, while in the second case the fit parameters are within the range of values observed in type I objects (, =1.7$\pm$0.2 and E_c=150^{+290}_{-66} keV); the statistics are however insufficient to discriminate between these two spectral shapes although a slightly better fit is obtained with reflection included. Comparison between NGC 4507 and other Seyfert galaxies indicate that although at low energies a difference between type I and II objects is possible (but still weak in this specific case) at high energies the observed shapes are indeed similar. We interpret this as evidence that the primary source emission (i.e. not reprocessed by material in the source) is the same for both types; this finding is in agreement with the unified scheme of Seyfert galaxies. Apart from its own interest, the OSSE detection of hard X-ray emission from a Seyfert II galaxy is also important for the implications it has on the contribution of Seyfert galaxies of both types to the cosmic diffuse background, as type II objects are expected to outnumber type I sources.

Subject headings: Galaxies:individual (NGC 4507)– Galaxies: Seyfert– X-rays: galaxies– Gamma-rays:observations

1. INTRODUCTION

The discovery by Antonucci and Miller (1985) that the polarized optical spectrum of NGC 1068 shows typical features of a Seyfert I galaxy, has represented a major step in the formulation of the so called "unified theory" of AGNs in general and Seyfert galaxies in particular. According to this theory, Seyfert II galaxies harbour a bright Seyfert I nucleus which is hidden from our view by an optically and geometrically thick obscuring torus. Consequently the difference between type I and II objects is only due to the viewing angle which determines whether the galaxy nucleus is seen directly or through a torus of molecular material and dust grains. X-ray data have provided further support to this picture. Recently, GINGA measurements have clearly demonstrated the existence in some type II objects of X-ray emission characterized by low energy photoelectric absorption corresponding to very high column densities of the order of $N_H \simeq 10^{23-24}$ cm^{-2} (Awaki and Koyama 1993; Awaki 1992). Hard X-ray/gamma-ray measurements, where the opacity of the blocking material is low, are extremely interesting as a further confirmation of the obscuration model as, in most cases, they offer the unique opportunity to observe directly the central emission and compare it to that of a Seyfert I. This observational evidence is also important with respect to the problem of the Seyfert contribution to the Cosmic Diffuse Background (CDB); as type II objects are expected to outnumber type I by a significant factor ($\sim$ 6) according to the unified model, they could overproduce the CDB unless in most sources the torus is thick to Compton scattering (Awaki 1991).
We report here OSSE/CGRO observations of the Seyfert II galaxy NGC 4507 recently discovered by GINGA to harbour an obscured X-ray source (Awaki et al. 1991, Awaki 1991). The X-ray continuum of this source is well described by a power law model with photon index , $\simeq 1.4$ and a high low energy cutoff ($\simeq$5 keV) corresponding to a column density of the obscuring matter of 5×10^{23} cm^{-2}, which is sufficient to hide the broad line region and the nucleus. The observed spectrum also shows an iron line having an equivalent width of $\sim$ 400 eV, which indicates a large covering factor for the matter around the nucleus (Awaki et al. 1991). Note also that EGRET has not detected NGC 4507 and that the 2 σ upper limit to the emission of nearby sources are at a level of $7 - 8 \times 10^{-8}$ photons cm^{-2} s^{-1} for energies above 100 MeV (Hartman 1994, private communication).

2. OBSERVATIONS AND RESULTS

A detailed description of the OSSE experiment as well as its performance and data analysis procedures can be found in Johnson et al. (1993). OSSE observed NGC 4507 on two separate occasions during 1993 (February 2-8 and August 10-17) for a total of 14 days. A total on source observation time for the sum of four detectors of 2.7×10^5 seconds of screened data were used in the analysis, while a similar amount of time was used for background monitoring. For this observation great care was taken to ensure that the bright radio galaxy Centaurus A which was near the edge of one background field did not contribute significantly to the background estimates. Despite this, background analysis gave some indication that Cen A might contribute at some level. However, when we looked at the response to Cen A this was found to be very small below 1 MeV, thus indicating that the effect we detected was probably due to orbital systematics at 1-2 σ level.
The source was detected at a significance level of 7σ from 50 keV up to 200 keV. A

Table 1: OSSE spectral fit results

Model	χ^2_ν/ν	Flux$^{(\dagger)}$	,	kT
Power Law	2.43/9	4.3±0.7	2.2±0.3	-
Exponential	1.32/9	5.2±0.7	-	51^{+13}_{-10}
Bremmss	1.53/9	5.1±0.7	-	95^{+31}_{-25}
Cutoffpl$^{(\ddagger)}$	1.76/9	4.9±0.7	1.4	139^{+93}_{-45}
Cutoffpl$^{(\ddagger)}$	2.12/9	4.7±0.7	1.9	319^{+1214}_{-159}

$^{(\dagger)}$ Flux at 100 keV in units of 10^{-6} photons cm^{-2} s^{-1} keV^{-1}

$^{(\ddagger)}$ Exponential cutoff power law with fixed photon index value

comparison between the two observing periods indicates no change in count rate on a timescale of 6 months (we detected 2.36±0.36 and 2.34±0.38 counts s^{-1} in February and August respectively). Furthermore, inspection of the daily average intensities for the sum of four detectors within each observation period confirms the constancy of the source flux. We have therefore combined data of the two observing periods to obtain the OSSE count spectrum. The data have been rebinned into 11 broad channels from 50 to 700 keV to improve the statistics and have then been fitted using the IGORE package with standard models for the incident photon spectrum. The results of the spectral fitting are shown in table I; the errors quoted in the table are 68% confidence limits for joint variation of the respective parameters of interest.

Fitting a power law model to the data gives a photon index of 2.2, in agreement with the OSSE average Seyfert spectrum (Johnson et al 1994). However with a χ^2 probability of 0.009 this model gives an unacceptable description of the data as also found in the case of NGC 4151 and of the average Seyfert spectrum obtained by OSSE (Maisack et al. 1993, Johnson et al. 1994). On the other hand, the data are much better described (χ^2 prob=0.22) by a simple exponential model having an e-folding energy of 51 keV. Although the exponential form has no meaning in terms of physical models, it is nevertheless a heuristic and useful description of the data and allows comparison of our data with other OSSE results, such as those mentioned above. Figure 1 shows the exponential fits to the OSSE data of NGC 4507 and, for comparison, of NGC 4151 and the average Seyfert spectrum: it is evident in the figure the similarity between the three spectra. Furthermore our value of kT is compatible with the average value of 46±5 keV reported for a sample of 15 Seyfert galaxies , mainly of type I (Johnson et al. 1994). An acceptable description of the data which has physical meaning is achieved by a thermal bremsstrahlung model having a temperature of 95 keV and a fit probability of 0.13. Marginally acceptable fits can also be achieved by an exponentially cutoff power law. Leaving the power law index as a free parameter gives a χ^2 probability of 0.17 but an unrealistic value of the photon index (, $= -0.1^{+5.6}_{-2.8}$); fixing , to 1.4 as observed by Ginga at lower energies gives a cutoff energy of 140 keV and a probability of 0.07. With the photon index fixed at a higher value (for example to 1.9 as observed in Seyfert I galaxies, (Nandra and Pounds 1994, Zdziarski et al. 1995, Madejski et al. 1995)) the cutoff energy increases to $\sim$ 300 keV and the fit becomes worse (χ^2 prob=0.02). We have also tried the thermal Comptonization model (Sunyaev & Titarchuk 1980) and found that for τ=3, as observed in NGC 4151, we obtained a temperature kT=44^{+7}_{-9} keV with a model probability of 0.2. The fit improves for higher values of the optical depth (up to τ=5-10), but then the data force the

temperature to unphysically low values.
The very soft spectrum observed by OSSE in 1993 is inconsistent with an extrapolation of the X-ray continuum seen by Ginga in July 1990. If we assume that the X-ray source spectrum remained unchanged over a three year period, then the OSSE data clearly requires that there is a steepening of the spectrum above 10 keV. In order to quantitatively define the overall shape we have simultaneously fitted OSSE and GINGA data using the XSPEC package. We have used Ginga channels between 2 and 20 keV (to exclude contamination by the instrumental silver line at 22-25 keV) as well as all OSSE data from 50 to 700 keV. We have modelled the broad band data with a power law having uniform neutral absorption, a Compton reflection component and an exponential cutoff. This spectral representation has been recently used to jointly fit Ginga-OSSE data (Madejski et al. 1995 and Zdziarski et al. 1995) as it can be explained in terms of thermal Comptonization models. The spectrum also contains an iron Kα emission line which we have modelled as a gaussian line. In the first instance we have assumed no reflection (f_r=0, where f_r is the relative normalization of reflection) and obtained as best fitting parameters a power law of photon index , =1.3$\pm$0.2 (errors are now quoted at the 90% level for a single interesting parameter), a low energy absorption corresponding to a column density of $N_H=(4.1 \pm 0.6) \times 10^{23}$, an iron line energy of $E_{Fe}= 6.3 \pm 0.1$ keV, a line flux $I_{Fe}= (2.2 \pm 0.6) \times 10^{-4}$ ph cm^{-2} s^{-1} (corresponding to an equivalent width,EW, of 330 eV) and a cutoff energy at $E_c=73^{+48}_{-24}$ keV (χ^2=1.10, for 34 d.o.f. corresponding to a model probability of 0.31). We have then fixed f_r=1 (this value is slightly less than that observed in Seyfert I galaxies and expected for face-on disk geometry (Nandra and Pounds 1994, Zdziarski et al. 1995, Madejski et al 1995) but more appropriate to Seyfert 2 galaxies where less reflection is predicted by the unified theory) and determine the other parameters. We find that in this case the absorbed power law steepens to , =1.7$\pm$0.2 (with $N_H=(4.4 \pm 0.6) \times 10^{23}$ cm^{-2}, $E_{Fe}=6.3 \pm 0.2$ keV,$I_{Fe} = (1.8^{+0.6}_{-0.7}) \times 10^{-4}$ ph cm^{-2} s-1, EW=247 eV) and the cutoff energy increases to $E_c=150^{+290}_{-66}$ keV. The χ^2 is now 1.06 and the fit probability becomes 0.38. Leaving f_r as a free parameter doe not change the fit and poorly constrain the amount of reflection to be $f_r=1.0^{+2.8}_{-1.0}$. The extrapolation of both models (with and without reflection) to high energies (> 100 MeV) is compatible with the EGRET upper limit. We have also tried to model the data without the exponential cut-off at high energies for both the case of f_r=0 and 1. In either case the model probability is worse (0.004 and 0.16 respectively) and its extrapolation to high energies is a factor 5-10 higher than the EGRET upper limit thus enforcing the use of an exponential cut-off in the model spectrum. In conclusion, the data quality is insufficient to clearly establish whether NGC4507 has a reflected component or not, although a slightly better fit is obtained with reflection included; moreover both fits are superior to the exponential fit to the OSSE data alone. The combined GINGA-OSSE spectrum for the case of f_r=1 is presented in figure 2. We have also obtained an upper limit for the annihilation line at 511 keV assuming a variable line width: the 90% confidence limit for a broad emission feature (modeled as a gaussian with 150 keV full width at half maximum) is 7.5×10^{-5} ph cm^{-2} s^{-1} keV^{-1}. This limit is width dependent and increases almost linearly by as much as a factor of 3.2 up to a width of 500 keV.

4. DISCUSSION

The main result of this work is the detection of high energy emission from a Seyfert II

galaxy as is observed in a type I object: NGC 4507 has a total 50-150 keV flux of 6.1 $\times 10^{-3}$ photons cm^{-2} s^{-1} MeV^{-1} corresponding to a luminosity $L \simeq 5 \times 10^{43}$ erg s^{-1} which is similar to that found in Seyfert I galaxies like IC4329A and others (Madejski et al. 1995, Maisack et al. 1993, Johnson et al. 1994). Furthermore the high energy spectral shape we measured is similar to that observed from the above mentioned type I objects. Together with SIGMA and/or OSSE observations of NGC 4388, NGC 1068 and MCG+5-23-16 (Lebrun et al. 1992, Johnson et al. 1994, Jourdain et al. 1994), our detection of NGC 4507 brings to four objects the sample of optically selected Seyfert II galaxies so far observed above 20 keV (note that some of the AGNs generally classified as Seyfert II are actually X-ray selected narrow emission line galaxies, or NELGs, somehow different from optically selected objects). While NGC 1068 and MCG+5-23-16 have not been detected at high energies, NGC 4388 has been found to be the dominant source of the Virgo cluster for energies greater than 10 keV. At even higher energies, EGRET upper limits have been reported for again only two type II Seyferts, namely NGC 1068 and MKN 348 (Lin et al. 1993). Comparison between 2-10 keV spectral data and high energy data indicates a spectral behaviour similar to that of NGC 4507 (a gradual spectral steepening towards high frequencies, Bassani et al. 1995, which is also present in NGC 1068 where the hidden nucleus is seen indirectly via electron scattering from a warm ionized medium located above the torus). Recently Zdziarski et al. (1995) on the basis of GINGA-OSSE data of NGC4507 and two other objects (classified as NELGs) have obtained an average broad band spectrum of Sey II galaxies from 2-500 keV. This work gives some evidence for a different spectral behaviour between the two types of Seyferts, in contrast to the unified theory: type II objects may have an intrinsically harder power law, show stronger neutral absorption, no or little reflection and an exponential cutoff at lower energies. However, this evidence is based on a limited sample of objects having slightly different characteristics and therefore cannot be taken as conclusive. Indeed our data on NGC4507 cannot exclude a broad band spectrum similar to Seyferts I. More high energy data on optically selected Seyferts II are needed to define this issue. In any case we can safely assume that the high energy (above 50 keV) spectrum of type II objects is indeed similar to type I sources. As in this energy range, we probe the primary emission mechanism not reprocessed by material in the source, our result indicates the presence of a similar central source in the two types and therefore argue in favour of the unified theory of AGNs. In NGC 1068 and similar objects, the torus must be considerably thick and our line of sight cannot be too far out of the equatorial plane: the source is defined as Compton thick. Thus the few available data suggest that some Seyfert IIs maybe characterized by high energy emission while others may not be (Compton thin and thick objects), and we are not yet able to quantify the percentage of sources in each group. According to the unified model, the number of Seyfert II galaxies should outnumber type I objects by approximately 6.5:1 (for a torus opening angle of 30°, Awaki 1991) thus making their combined emission an extremely important contributor to the CDB also at high energies. Assuming that Seyfert I galaxies produce $\simeq$ 20% of the CBR even above 50 keV (this is not an unreasonable assumption if one extrapolates the results of Rothschild et al. 1983 but breaking the average Seyfert spectrum at 50 keV to a steep power law of photon index 2.2 as suggested by OSSE results), then we may be confronted with the problem of the overproduction of the CBR by the Seyfert component (type I plus type II objects). One possible solution would be to assume that a significant fraction (40% or more) of Seyfert IIs are Compton thick so that no hard X-rays get out, like it is observed in NGC 1068

and MCG+5-23-16. Viceversa, if this is not applicable (i.e. most sources are like NGC 4507 and NGC 4388), then the CBR constrains the number of Seyfert II to scale that of Seyfert I by approximately 3:1 to allow both evolution effects and contribution from other type of objects to be considered. It will be extremely important to this end to search for high energy emission from an extended sample of Seyfert II galaxies using the capabilities of instruments onboard the Compton Gamma-Ray Observatory.

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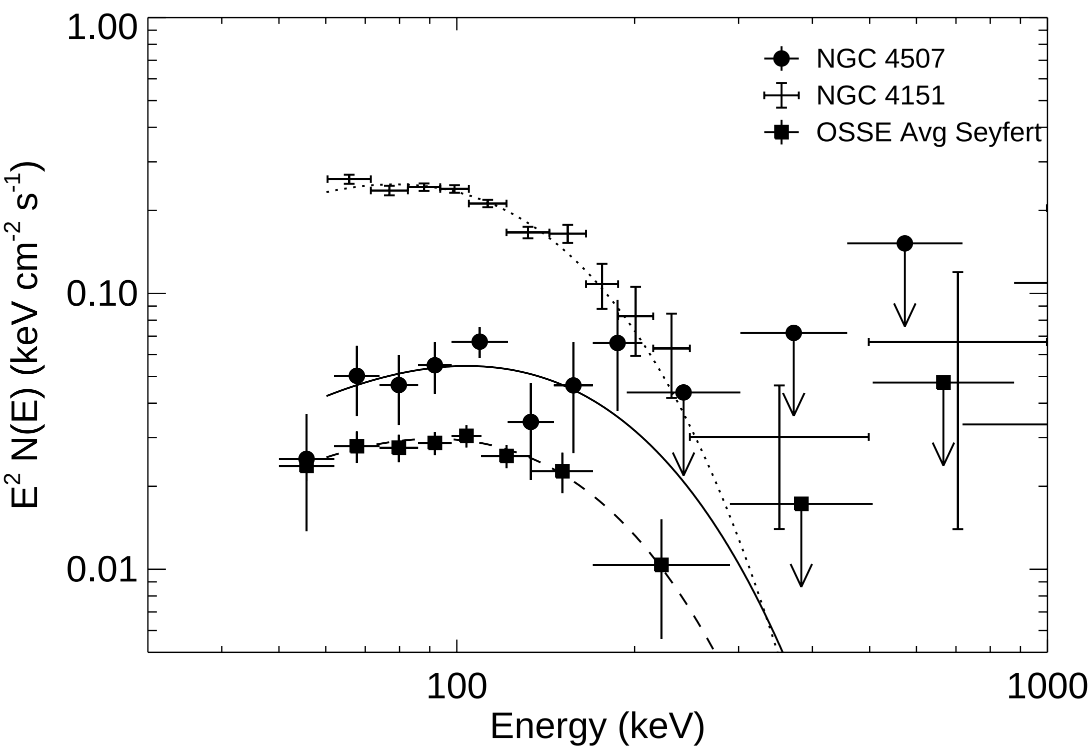

Figure 1: The OSSE spectrum in (EFE) of NGC 4507 compared to those of NGC 4151 (Maisack et al. 1993) and of the average Seyfert (Johnson et al. 1994) obtained by the same instrument; the three curves correspond to exponential best fits to the individual data sets.

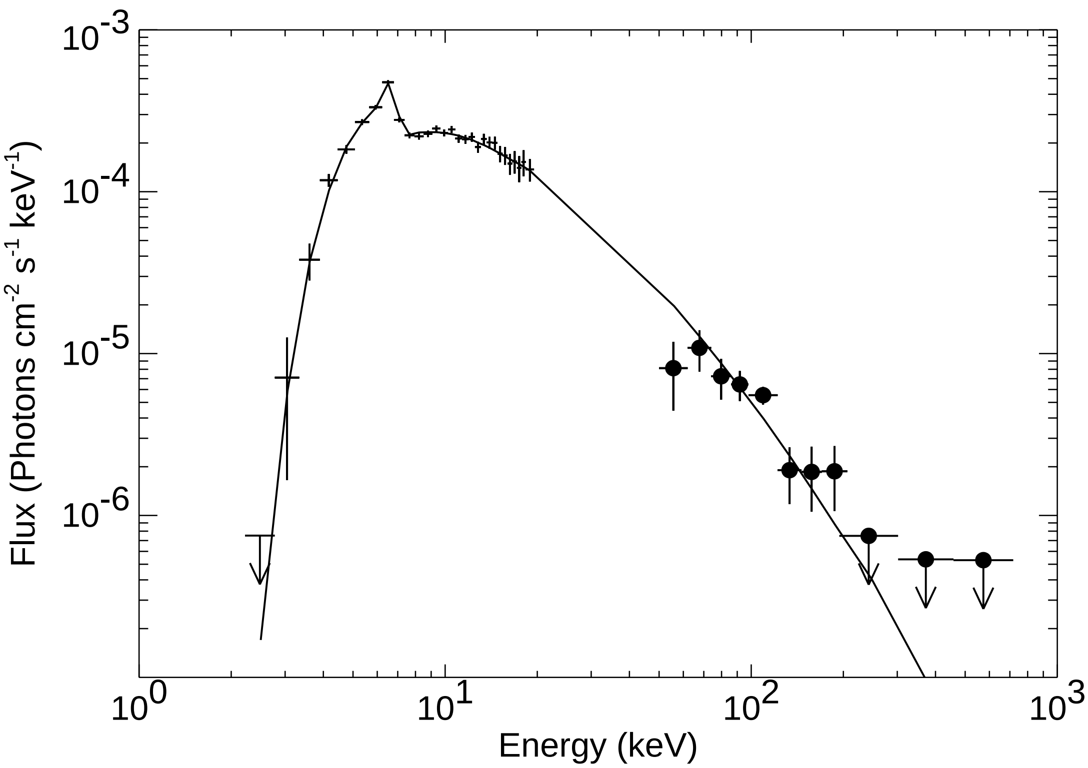

Figure 2: Joint GINGA/OSSE photon spectrum for NGC4507 (single data points and continuous line corresponds to a model consisting of an underlying power law with an exponential cutoff plus reflection $f_{/rmr}$=1, uniform neutral absorption and an iron Kα emission line). Note that the observations were not simultaneous (GINGA 1990, OSSE 1993).